

# Traction Drive Systems with Integrated Wireless Charging

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# Overview

## Timeline

- Start – FY15
- End – FY17
- 17% complete

## Budget

- Total project funding
  - DOE share – 100%
- Funding for FY15: \$250K

## Barriers

- Reducing the cost, weight, and volume of electric drive systems with integral wireless battery functionality
- Achieving high efficiency

## Partners

- International Rectifier/Infineon, Delphi, GaN Systems, Ferroxcube, NREL
- ORNL team members: Madhu Chinthavali, Omer Onar, Zhenxian Liang, Cliff White, Jack Wang

# Project Objective and Relevance

- **Overall Objective**

- Redesign electric drive system to include wireless charging functionality and reduce cost; increase efficiency and power density using WBG devices.

- **FY15 Objective**

- Develop converter topologies suitable for redesigning traction drive systems to include wireless charging functionality and control strategies for minimizing component size and circuit losses through detailed circuit simulation.

# Milestones

Date	Milestones and Go/No-Go Decisions	Status
Month 2014	<u>Milestone</u> : new start	
Month 2014	<u>Go/No-Go decision</u> : new start	
Sept. 2015	<u>Milestone</u> : Complete topology selection through simulation study	On track
Sept. 2015	<u>Go/No-Go decision</u> : If simulation results show potential to meet efficiency goal, proceed to develop prototypes.	

# Problem to be Addressed

## State of the Art

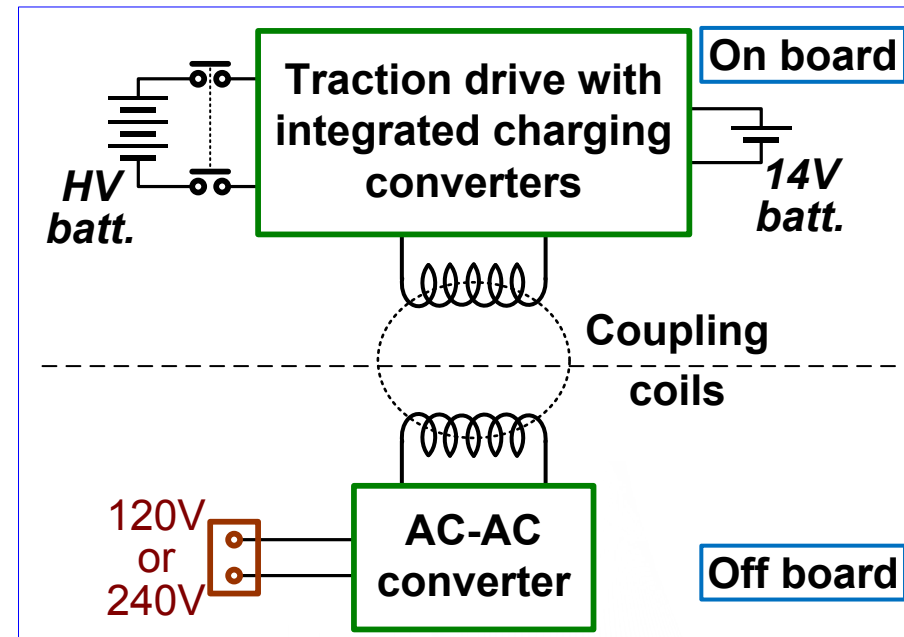
- Existing plug-in electric vehicles (PEVs) employ individually optimized converters for
  - the electric traction drive
  - the wired battery chargers (high voltage and 14V batteries)  
leading to large component count, system weight, volume, and cost
- Wireless chargers enable convenient, safe, and automated charging without need for cable and plug and can maximize electric vehicle (EV) mileage; however they
  - add cost, weight, and volume to PEVs
  - have relatively low wall-to-battery efficiencies with existing designs

***Redesign Electric Drive System with Wireless Charging Functionality***

# Approach

## Strategy to Address Limitations of SOA

- Minimize PEV system components and cost through functional integration of onboard power electronics for vehicle propulsion and wireless battery charging
- Increase efficiency and further reduce weight and volume by optimizing converter topology and coil design and using wide bandgap (WBG) devices
  - Wireless charging efficiency: >92%



Conceptual block diagram for a traction drive system with wireless charging functionality

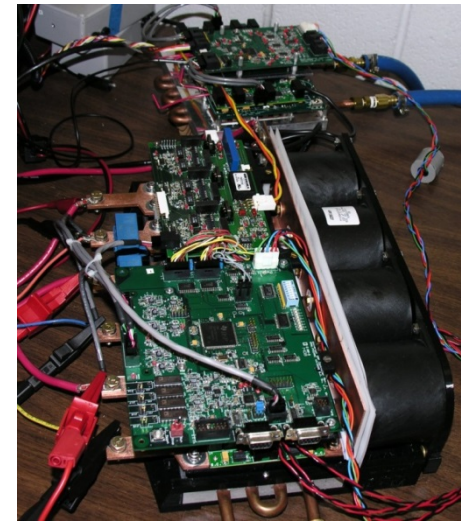


# Approach

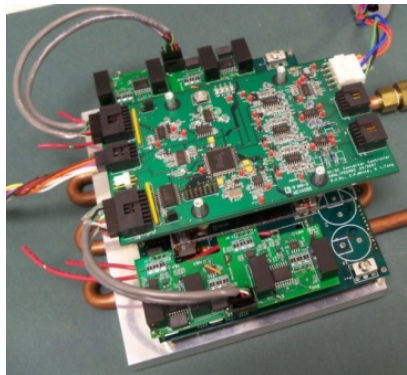
## Strategy to Address Limitations of SOA

This work builds upon ORNL's previous work on traction drive, on-board charger (OBC), and wireless charger

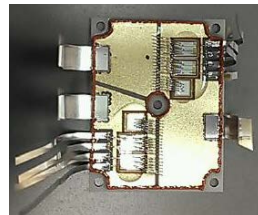
- Demonstrated a 6.6 kW bidirectional SiC-based isolation converter that has a built-in 2 kW 14 V buck converter with peak efficiency of 99%
- Demonstrated a bidirectional 6.6 kW SiC-based OBC and dc-dc converter
  - 47% reduction of components for the power circuit components alone without counting savings in the gate driver and control logic circuits
  - Peak charging efficiency of 96.5 % at 240 V input



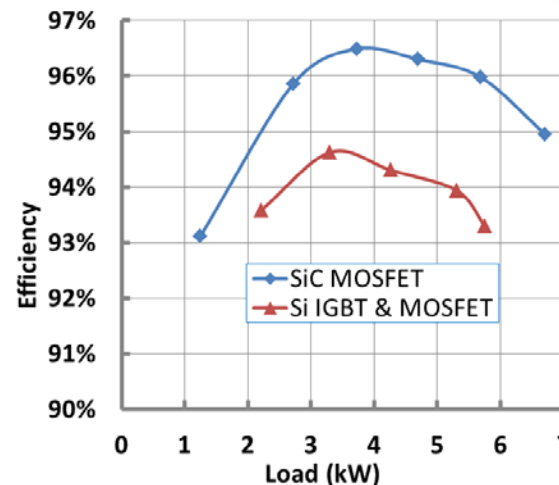
SiC traction drive inverter with an integrated 6.6 kW OBC



6.6 kW SiC isolation converter



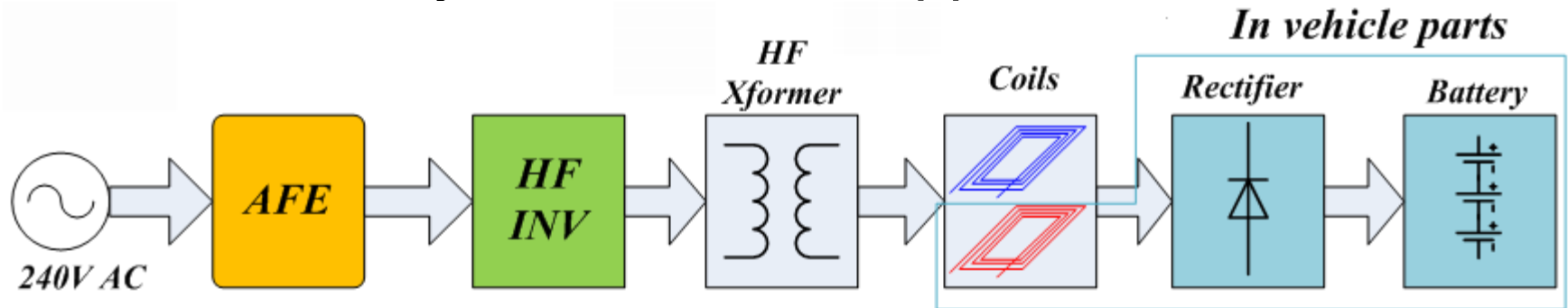
ORNL SiC module  
1200 V  
100 A



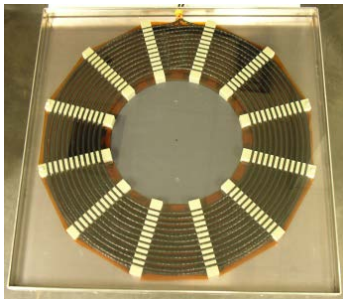
OBC system efficiency for the SiC 6.6 kW integrated charger

# Approach Strategy to Address Limitations of SOA

- ORNL demonstrated several add-on wireless chargers capable of up to 10 kW continuous charging power for both stationary and in-motion applications



ORNL's wireless chargers operating at 22-26 kHz



Coils



Stationary wireless  
charging of a Prius PHEV



In-motion wireless  
charging of a GEM® EV



# Approach

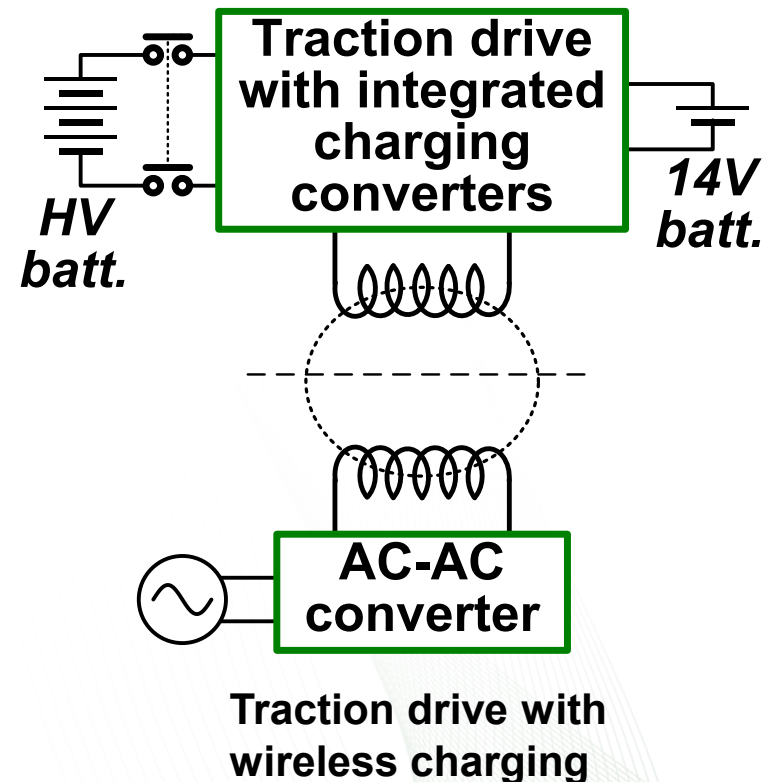
## Strategy to Address Limitations of SOA

- **Select converter topologies for traction drive with wireless charging that can meet cost and performance goals**

- Review and compare published electric drive systems
- Simulate new topologies

- **Improve wireless charging efficiency and meet health and safety requirements**

- Design optimization for converter and resonant circuit using WBG devices
- Optimal control strategy to reduce resonant current
- Coil design for maximum coupling coefficient and minimum fringe field level through novel geometry and optimization of coils and ferrite shields



# Approach Strategy to Address Limitations of SOA

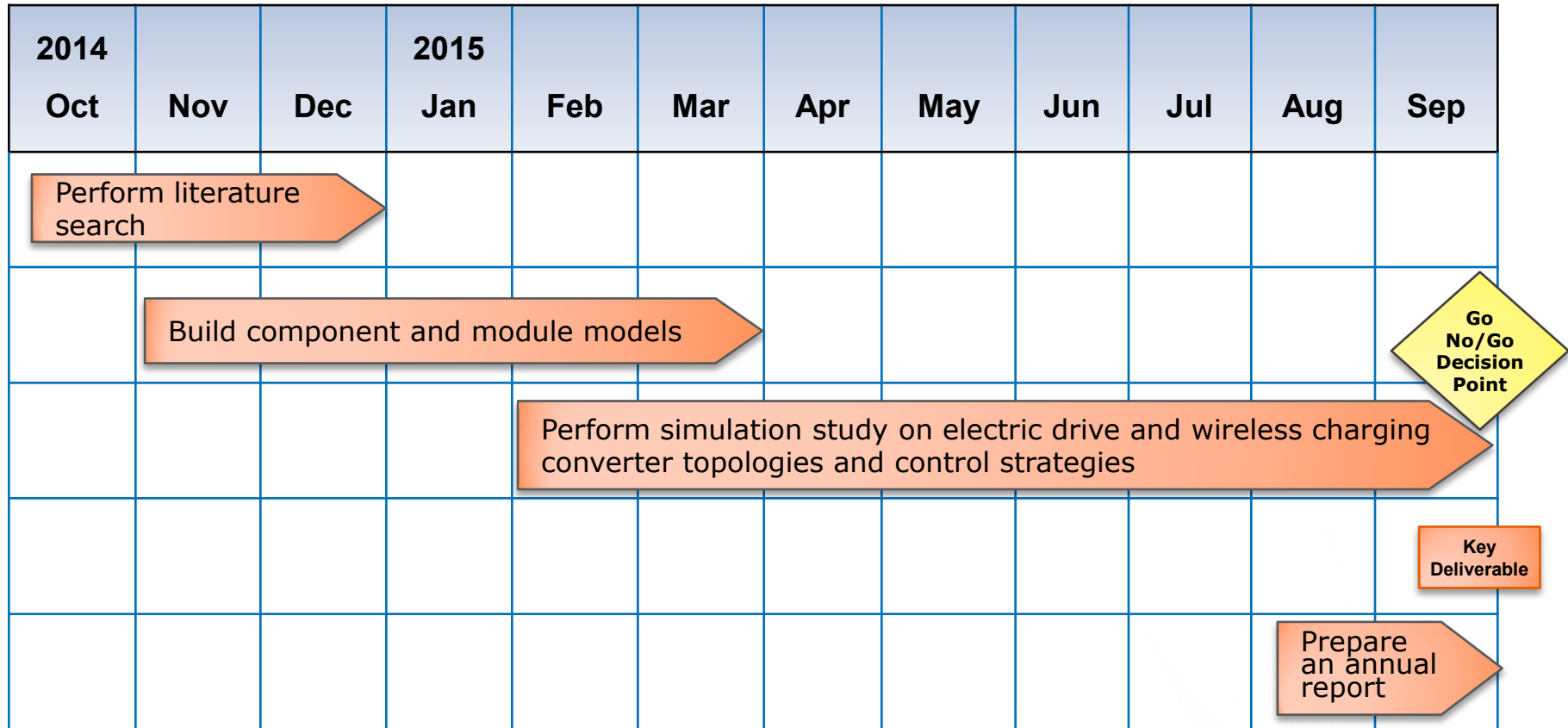
- **Uniqueness**

- Leveraging ORNL's extensive past and current work on wireless chargers and traction drives to redesign the electric drive system with wireless charging functionality
- Utilizing ORNL's expertise and facility in converter design, packaging, and testing to fully take the advantage of WBG devices in PEV applications

- **Impact**

- Successful demonstration of a electric drive system that incorporates wireless charging and WBG devices will provide a technological path for commercialization
- Low cost and high efficiency electric drive system with wireless charging

# Approach FY15 Timeline

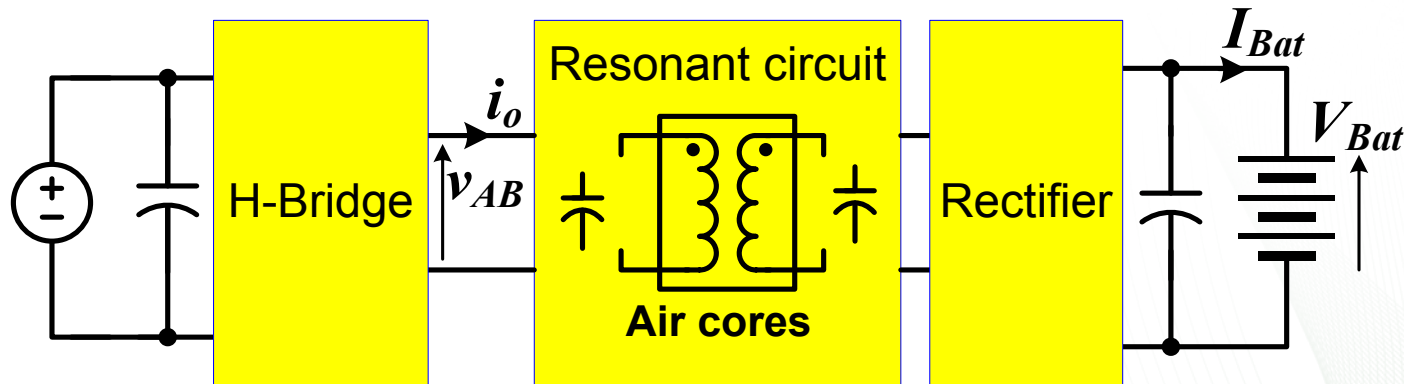


**Go No/Go Decision Point:** If simulation results show potential to meet efficiency goal, proceed to develop prototypes.

**Key Deliverable:** Annual report including research findings on electric drive topologies with wireless charging and simulation results

# Technical Accomplishments – FY15

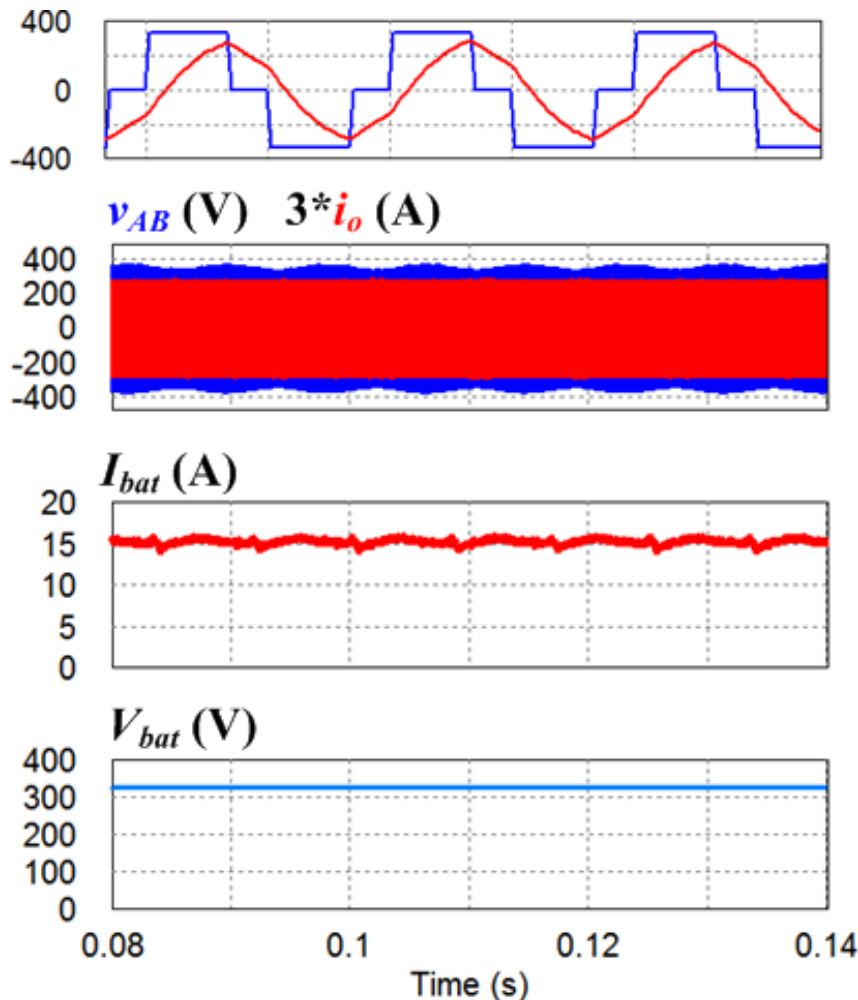
- Conducted literature review on resonant circuits for wireless charging
- Simulated various resonant circuits and designed one that is optimized for minimizing reactive power requirement by increasing load power factor and reducing circulating current
  - Series
  - Parallel
  - Combinations of series and parallel



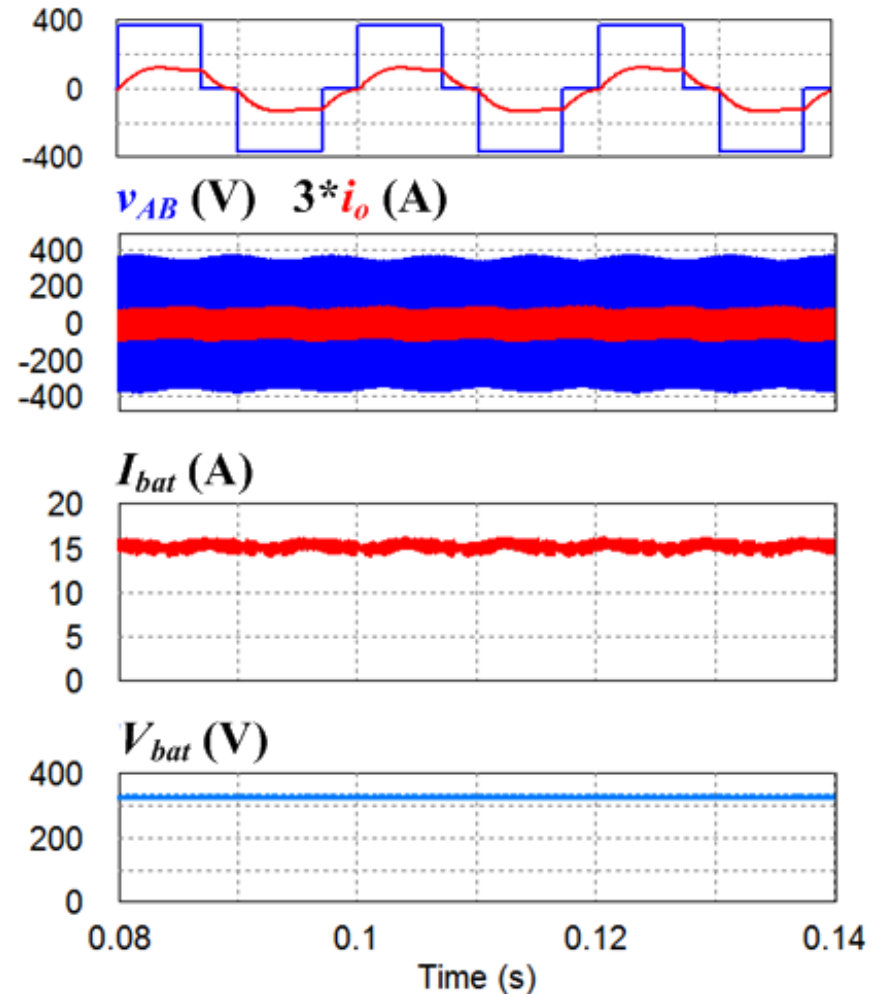
Simplified converter block diagram for studying resonant circuits

# Technical Accomplishments – FY15

- Designed a resonant circuit optimized for increasing load power factor and reducing resonant current



Traditional resonant circuit  
with low load power factor

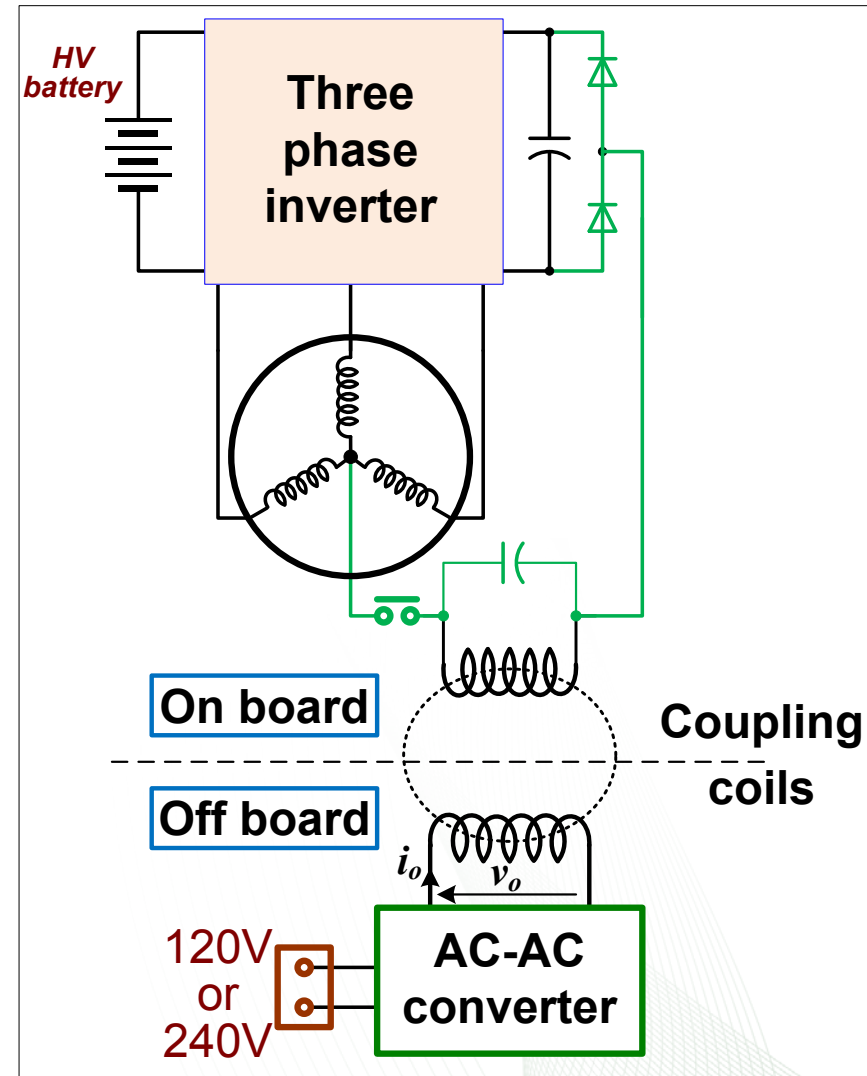
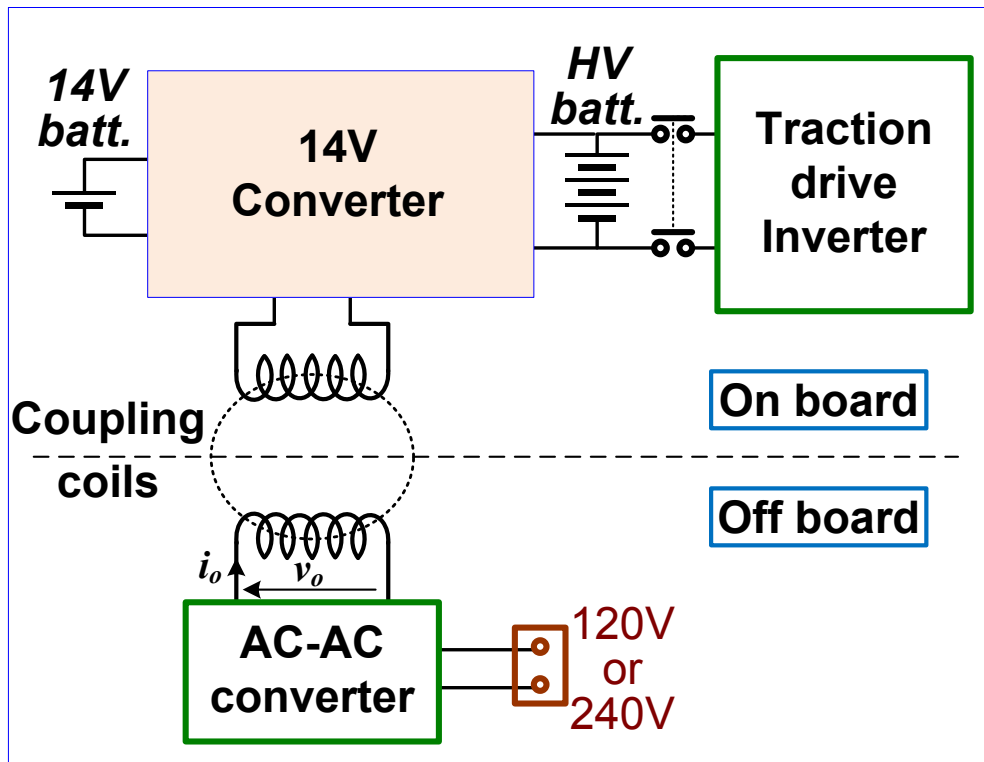


Optimized resonant circuit  
with high load power factor

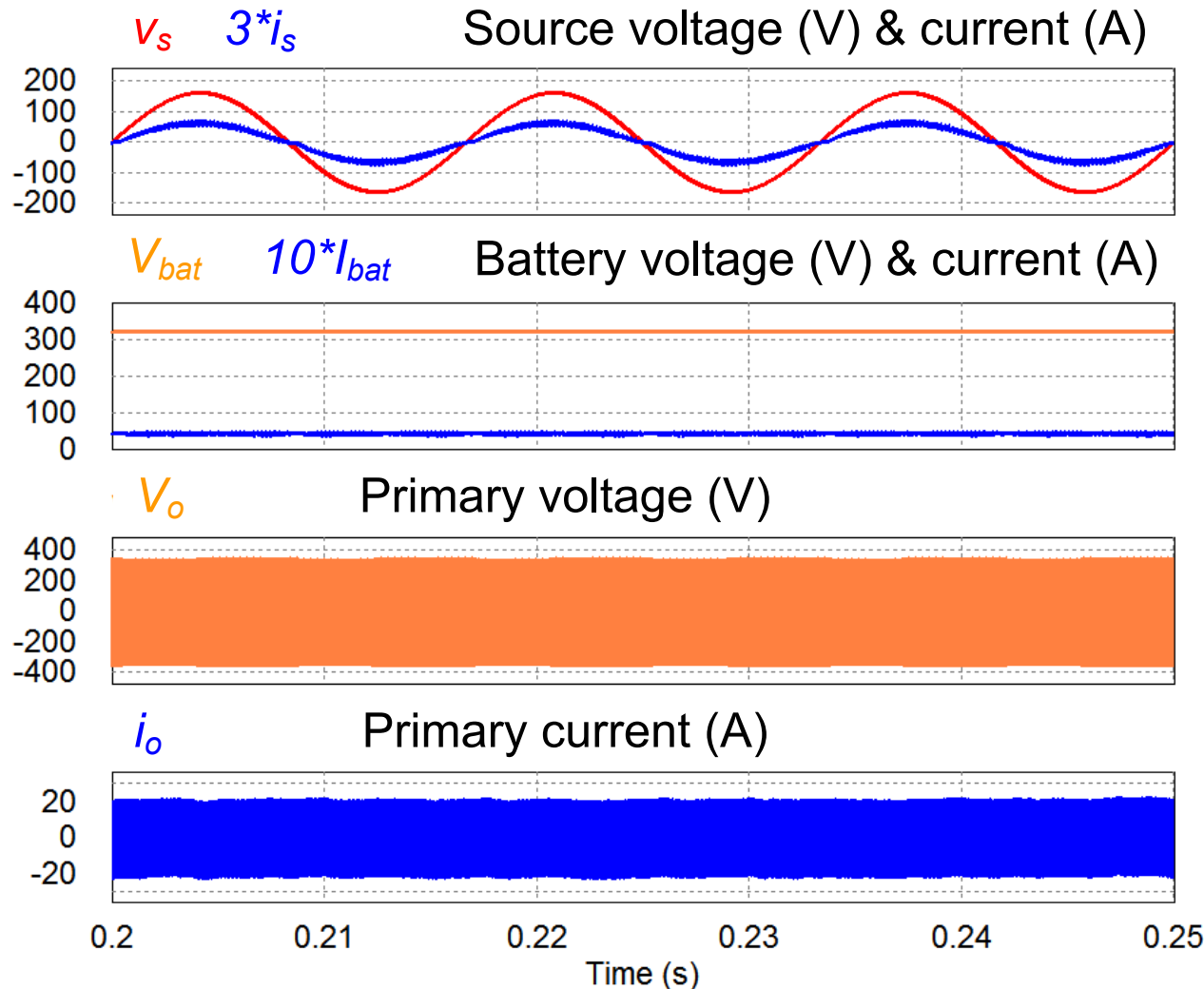


# Technical Accomplishments – FY15

- Built component and module models
- Simulated two topologies
  - #1: Tapping into the 14V converter
  - #2: Utilizing the traction motor and inverter

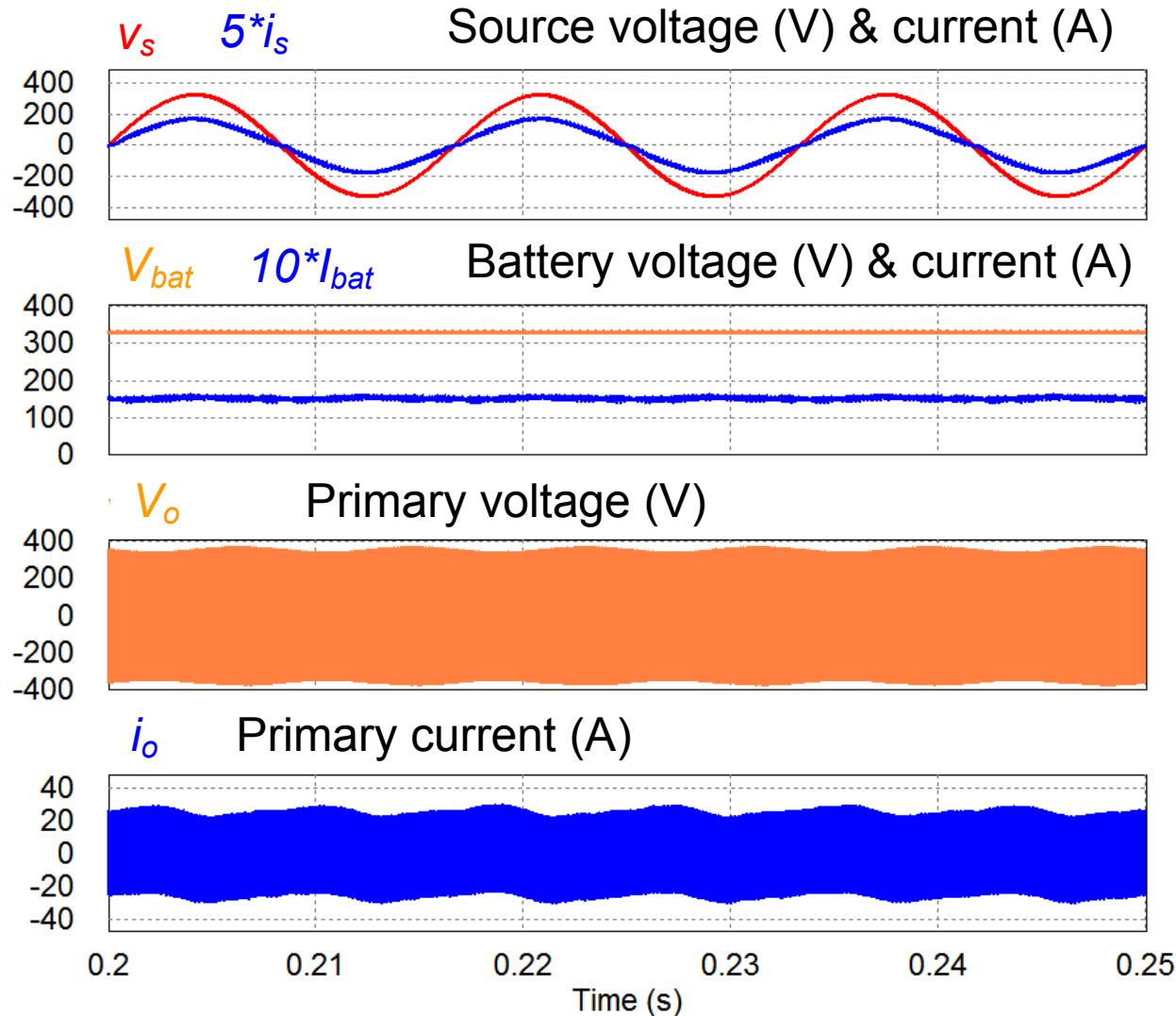


# Technical Accomplishments – FY15



- **Simulation results for topology #1**
  - charging at 1.5 kW from 120V source
  - Proved the concept
  - High input power factor and low current distortion

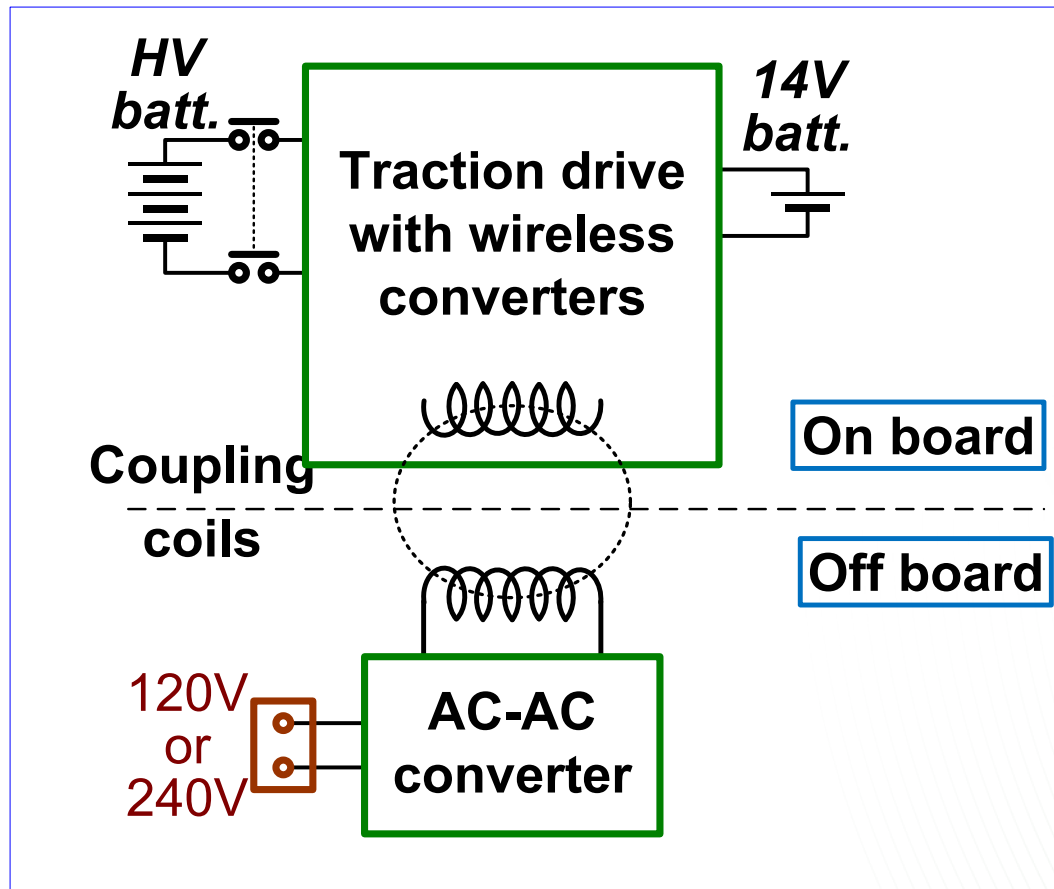
# Technical Accomplishments – FY15



- **Simulation results for topology #2**
  - charging at 5 kW from 240V source
  - Proved the concept
  - High input power factor and low current distortion

# Technical Accomplishments – FY15

- Topology study
  - Next step: Redesign Electric Drive System with Wireless Charging Functionality



# Responses to Previous Year Reviewers' Comments

- **This project is a new start.**



# Partners/Collaborators

- International Rectifier/Infineon — GaN devices and modules, requirements for gate drivers
- Delphi — GaN power modules
- GaN Systems — 600V GaN switches
- Aegis Technology Inc. — light-weight, low loss nano-magnetic materials
- Ferroxcube — Input on design and fabrication of high frequency soft ferrites
- NREL — Input on thermal management design

International  
**IOR** Rectifier

**DELPHI**

**GaN** Systems

 **FERROXCUBE**  
A YAGEO COMPANY

 **EGIS TECHNOLOGY, INC.**

 **NREL**  
NATIONAL RENEWABLE ENERGY LABORATORY

 **OAK RIDGE**  
National Laboratory

# Remaining Challenges and Barriers

- Need unconventional electric drive topologies that can provide wireless charging capability as an integral function
  - Several ideas are being investigated through circuit simulation
- Achieve higher efficiency comparable to wired OBCs

# Proposed Future Work

- **Remainder of FY15**

- Complete topology simulation study

- **FY16**

- Design, build, and test a 3.3 kW wireless charging module as part of a 55 kW electric drive system

- **FY17**

- Design, build, and test a 55 kW electric drive with wireless charging capability of 3.3 kW.
- Scale up the design, build, and test a 6.6 kW wireless charging module.

# Summary

- **Relevance:** This project is targeted at redesigning the electric drive system to provide wireless charging as an integral function at low cost and high efficiency.
- **Approach:** Minimize PEV system components and cost through functional integration of onboard power electronics for vehicle propulsion and wireless battery charging and increase efficiency and further reduce weight and volume by optimizing converter topology and coil design and using wide bandgap (WBG) devices.
- **Collaborations:** Discussions have been held with several industry stakeholders to maximize the impact of this work.
- **Technical Accomplishments:**
  - Simulated and proved concepts of several electric drive topology candidates with integrated wireless charging functionality.
  - Simulated various resonant circuits and designed one that is optimized for minimizing circulating current and the associated losses.
- **Future Work:** Select an electric drive topology that can provide wireless charging capability as an integral function; design, build and test WBG based prototypes; Once proof-of-concept hardware development is complete, collaborate with and/or transfer technology to industry.